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RELIABILITY AND MAINTAINABILITY BLOCK DIAGRAMS AND MATHEMATICAL--ETC(U)

MAR 77 E W KING N62269-76-C-0341

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Mission Reliability

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document defines the maintainability block diagrams, and math models, and reliability block diagrams for the externally mounted, automatically expelled/inflated multiplace life raft for helicopters (Automated Life Raft (ALR)). These diagrams and models serve as a basis for estimating the effectiveness of the life raft as a survival system, and will be used in allocation, prediction, and failure modes and effects analysis.

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ABSTRACT

This document defines the maintainability block diagrams and math models and reliability block diagrams for the externally mounted, automatically expelled/inflated multiplace life raft for helicopters (automated life raft (ALR)). These diagrams and models serve as a basis for estimating the effectiveness of the life raft as a survival system and will be used in allocation, prediction and failure modes and effects analysis.

KEY WORDS

Block Diagram
Math Model
Hardware Breakdown Structure (HBS)
Planned Maintenance
Special Inspection
Phased Inspection
Maintenance Downtime
Turnaround Inspection
Flight Safety Reliability
Mission Reliability
Maintenance Malfunction Reliability

ABBREVIATIONS

ALR	Automated Life Raft
WRA	Weapons Replaceable Assembly
BCM	Beyond Capability of Intermediate Maintenance (Item Condemned)
BCM1-8	Beyond Capability of Intermediate Maintenance (Item Shipped to Depot Level)
MH/FH	Man-hour per Flight Hour
λ	Maintenance Action Rate per 1000 Flight Hours
ET	Elapsed Time in Minutes
CREW	Average Number of Men Required for the Maintenance Action
TURNAROUND	Performed Every Two Flight Hours and $\lambda = 500/1000$ FH
SPECIAL	Performed Every 28 Days or 38.4 Flight Hours and $\lambda = 26.042$ per 1000 Flight Hours
PHASE	Performed Every 400 Flight Hours and $\lambda = 2.5$ per 1000 Flight Hours

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LIST OF FIGURES

1. MAINTAINABILITY BLOCK DIAGRAM AND MATHEMATICAL MODEL

The Automated Life Raft (ALR) installation by its nature as survival equipment is not normally exercised during routine flight operations and hence its impact on overall system operational readiness may be considered as insignificant. This parameter, considered herein as synonymous with availability, is assessed by the following model and later quantified as a part of maintainability allocations and predictions. Preventive or scheduled maintenance comprises the major portion of the installation maintenance burden and is addressed at both organizational and intermediate levels of maintenance by the model. Corrective maintenance is treated in a like manner and as a result the block diagram and maintainability model can be used to determine the character and magnitude of the ALR installation maintenance downtimes and maintenance support demands at the organizational and intermediate levels of maintenance.

2: ALR HARDWARE BREAKDOWN STRUCTURE (HBS)

The HBS affords a graphic display of the end item subdivided into successively smaller units. Each unit is identified with a summary number conforming to the requirements of MIL-STD-780, "Work Unit Codes and Maintenance Engineering Analysis Control Numbers (MEACNS) for Aeronautical Equipment; Uniform Numbering System". This number is used for Logistic Support Analysis (LSA) identification during design and development, and for maintenance reporting during operational use, thus closing the loop of Allocation, Prediction, Demonstration and Evaluation.

Figure 1 shows the ALR installation interfaced with a segment of the existing HBS of the H-46 helicopter as contained in NAVAIR 01-250HD-8, "Work Unit Code Manual H-46 Aircraft". As indicated the ALR installation as presently envisioned contains three Weapon Replaceable Assemblies (WRA's): Life Raft Container, Cockpit Control and Cabin Control. It should be noted that the major contents of the Life Raft Container, the first four Shop Replaceable Assemblies (SRA's), are Government Furnished Equipment (GFE). These GFE components are included in this maintainability assessment to provide a true evaluation of the overall ALR installation maintenance burden. The added electrical components and wiring are considered in this model, recognizing that operational maintenance would be reported under the Electrical work unit code of 42000. Any of the ALR summary numbers may be used to exercise the maintainability model.

3. ALR MAINTAINABILITY BLOCK DIAGRAM

The top level maintainability block diagram for the ALR is shown in Figure 2. This diagram indicates <u>what</u> maintenance must be performed and <u>why</u> it is performed. Applying this rationale to lower levels of installation indenture results in the definition of maintainability analysis work packages, i.e. how can maintainability techniques reduce the support burden of required maintenance?

ALR HARDWARE BREAKDOWN STRUCTURE

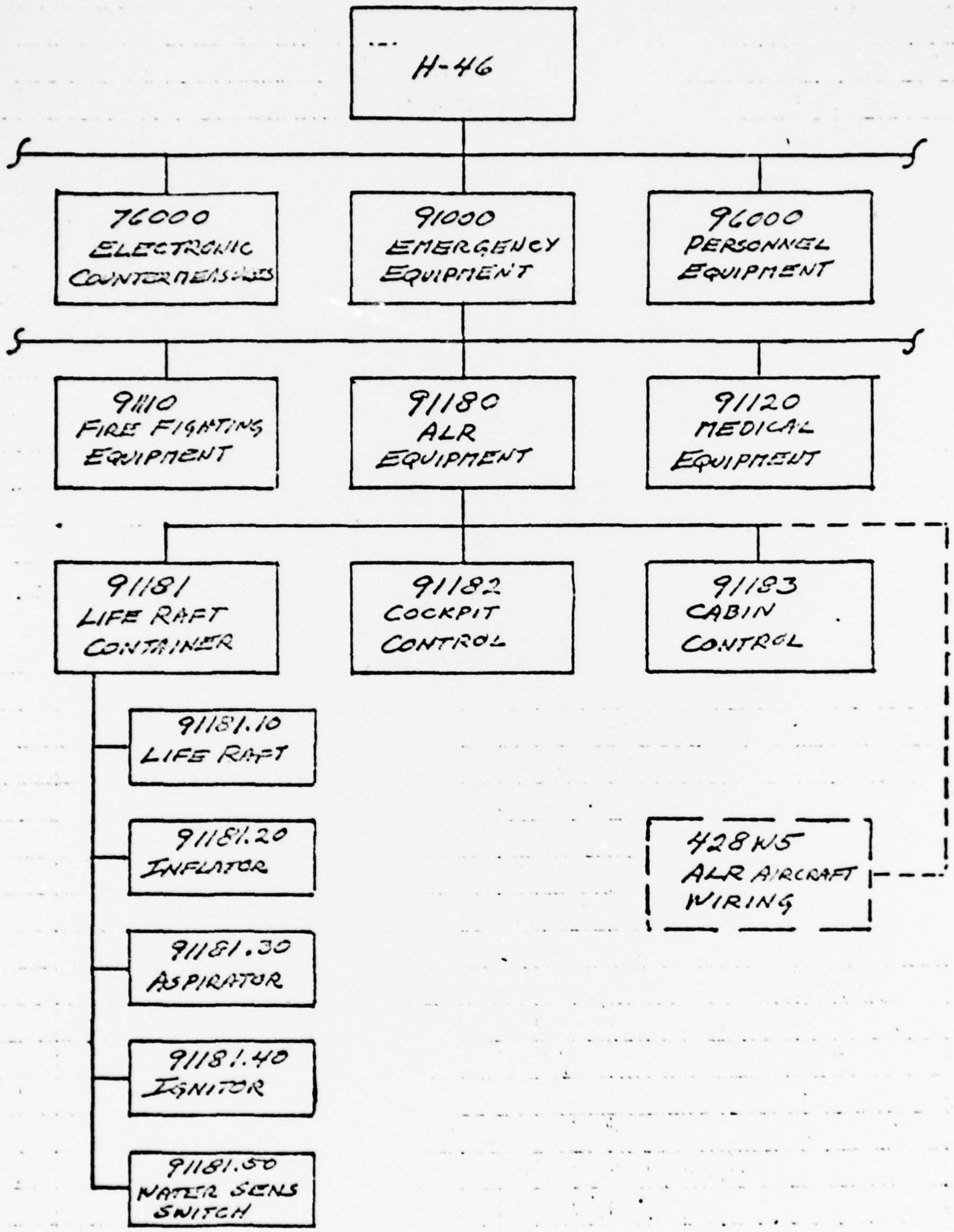
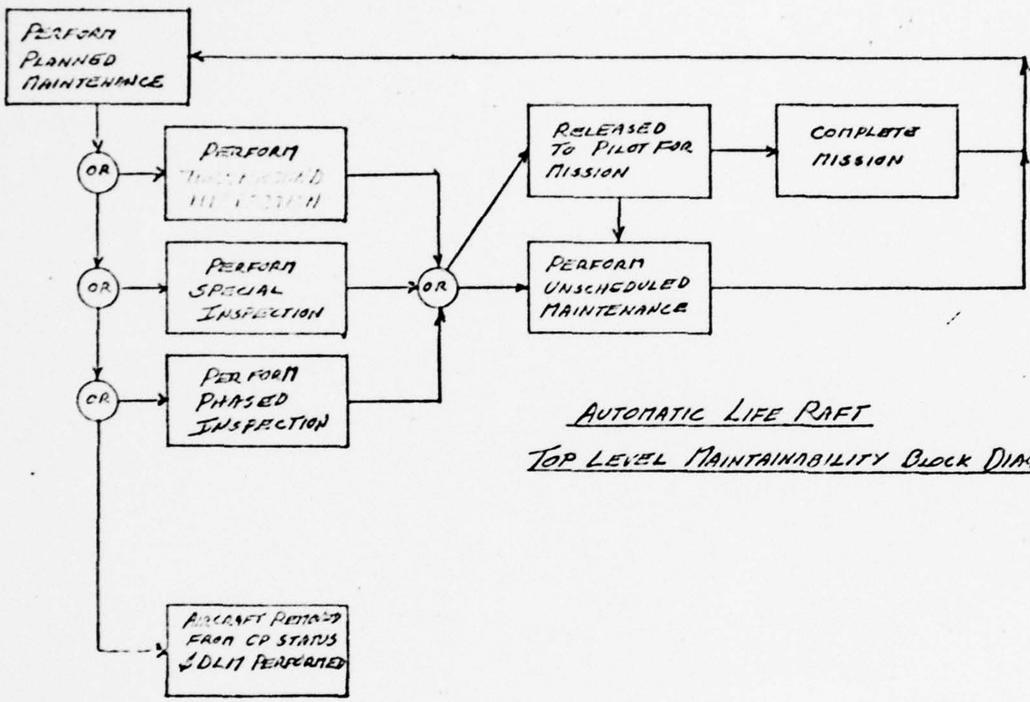


Figure 1



AUTOMATIC LIFE RAFT

TOP LEVEL MAINTAINABILITY BLOCK DIAGRAM

Figure 2

4. PLANNED MAINTENANCE

The Planned Maintenance Block of the diagram refers to the planned maintenance requirements of The Naval Aviation Maintenance Program (NAMP) as defined in Chapter 11, Volume II of OPNAVINST 4790.2A. The ALR installation support is based on the requirements of the ALR with their rationale are defined in the following paragraphs.

4.1 TURNAROUND INSPECTION

This inspection is conducted prior to the first flight of each day and each subsequent flight to ensure the integrity of the ALR installation. Since the ALR system has a built in test capability which is exercised as part of the pilot's preflight check list, the maintenance turnaround is limited to a visual inspection of the Life Raft Container for security and obvious damage.

4.2 SPECIAL INSPECTION

A special inspection is an inspection with a prescribed interval other than preflight, post flight, daily, turnaround, calendar/phased or SDLM (Standard Depot Level Maintenance). This inspection may or may not be required for the ALR, however it shall be considered when analyzing the final design configuration of the ALR installation. The driving consideration necessitating this inspection is the probability that the installation does not unacceptably degrade with time between complete functional checkouts. Complete functional checkout is planned during the H-46 Phase Inspection which equates to a 400 flight hour interval between checkouts. Dependent on aircraft utilization the calendar time between checkouts will be from 5 to 20 months with 10 to 12 most probable. Current ALR concepts may use water sensing switches as part of the automatic actuation. These switches do not have a very reliable performance history and, should they be used, a Special Inspection at 28 day intervals would be established to test these switches for proper operation. Hence the need for, and the interval of, this Special Inspection, shall be dependent on final ALR design configuration.

4.3 PHASED INSPECTION

The H-46 helicopter phased inspection is a series of four related inspections that are performed sequentially at 100 hour intervals. One of these phases shall include a comprehensive inspection of the ALR installation. The life raft container will either be replaced or removed, inspected, and tested at the intermediate level of maintenance and re-installed on the aircraft. This action will ensure that the GFE container will be maintained in accordance with NAVAIR 13-1-6.1, "Aviation-Crew Systems Manual, Inflatable Survival Equipment". While the container is removed all ALR aircraft wiring will be inspected and checked out. The intermediate level requirements shall be per the NAVAIR Manual.

4.4 CORRECTIVE (UNSCHEDULED) MAINTENANCE

Corrective maintenance is a result of discrepancies noted during planned maintenance or reported by pilots after unsuccessful pre-flight test. The latter represent an impact on overall H-46 helicopter availability and hence maintainability features of ALR design shall receive special attention in this area.

5. MAINTAINABILITY MATHEMATICAL MODEL

Figure 3 is a flow chart of the math model used to drive maintainability quantitative parameters. Abbreviations, constants and variables are defined as follows:

WRA	Weapons Replaceable Assembly
BCM9	Beyond Capability of Intermediate Maintenance (Item condemned)
BCM1-8	Beyond Capability of Intermediate Maintenance (Item shipped to Depot level)
MH/FH	Manhours per Flight Hour
λ	Maintenance Action Rate per 1000 Flight Hours
ET	Elapsed Time in Minutes
CREW	Average number of men required for the maintenance action
TURNAROUND	Performed every two flight hours and λ = 500 per 1000 flight hours
SPECIAL	Performed every 28 days or 38.4 flight hours and λ = 26.042 per 1000 flight hours
PHASE	Performed every 400 flight hours and λ = 2.5 per flight hours

5.1 MAINTENANCE DOWNTIME

ALR preventive maintenance is performed concurrent with existing H-46 preventive maintenance requirements and hence has no effect on aircraft downtime. ALR Mean Maintenance Downtime (MMDT) and Maintenance Downtime per Flight Hour (DT/FH) are computed as follows:

$$MMDT = \frac{((\text{Repair } \lambda * \text{Repair ET}) + (\text{Replace } \lambda * \text{Replace ET}))}{((\text{Repair } \lambda + \text{Replace } \lambda)*60)}$$

$$DT/FH = \frac{((\text{Repair } \lambda * \text{Repair ET}) + (\text{Replace } \lambda * \text{Replace ET}))}{(1000*60)}$$

5.2 ORGANIZATIONAL MAINTENANCE MANHOURS PER FLIGHT HOUR (ORG MH/FH)

ORG. MH/FH is a summation of preventive (PREV ORG MH/FH) and corrective (CORR ORG MH/FH) times, and is computed as follows:

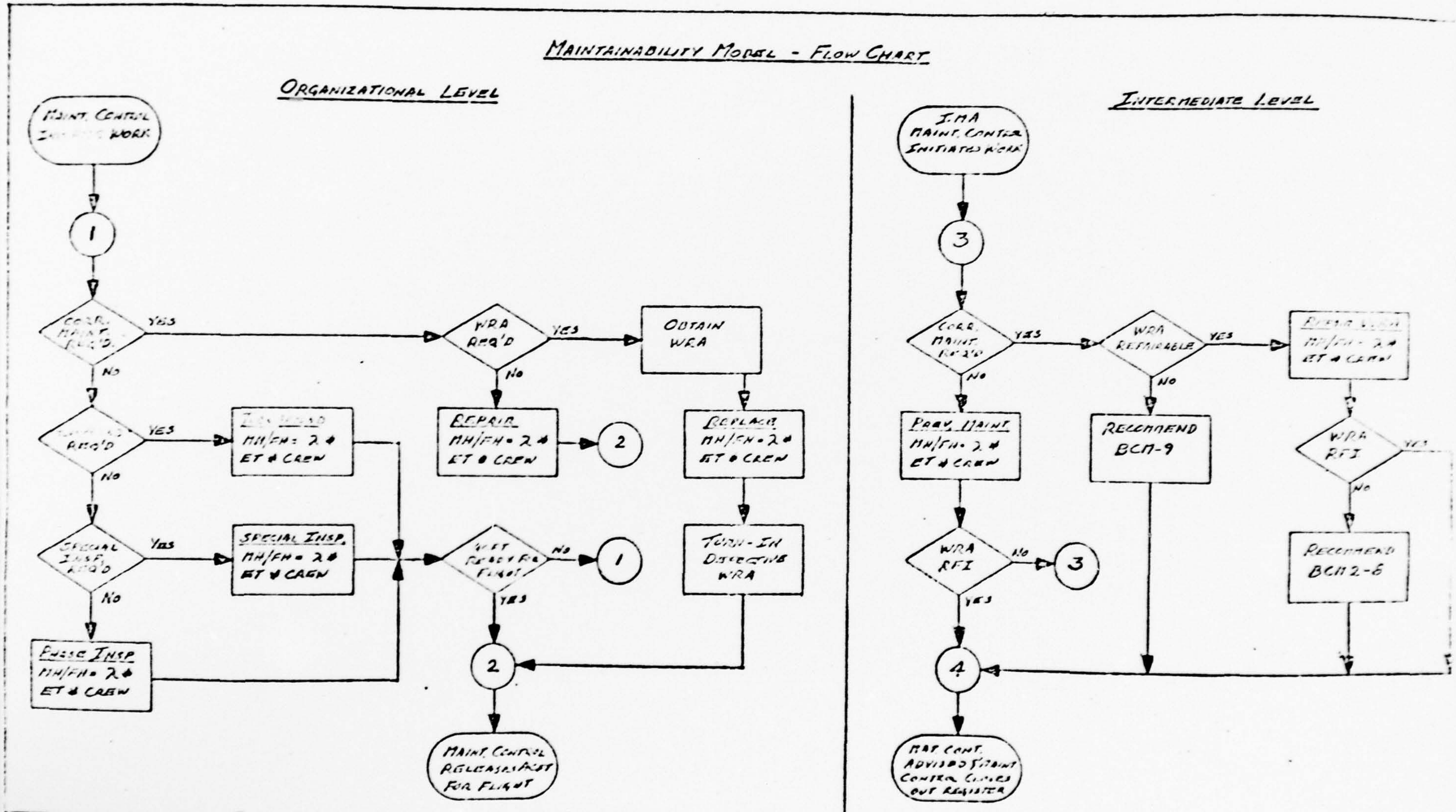

MAINTAINABILITY MODEL - FLOW CHART
ORGANIZATIONAL LEVEL
INTERMEDIATE LEVEL
OBTAIN WRA
WRA REQ'D
YES
NO
REPAIR MH/FH = λ ET # CREW
REPLACE MH/FH = λ ET # CREW
SPECIAL INSP. MH/FH = λ ET # CREW
PHASE INSP MH/FH = λ ET # CREW
TURN-IN DEFECTIVE WRA
MAINT. CONTROL RELEASES A/C FOR FLIGHT
I.MA MAINT. CONTROL INITIATES WORK
CORR. MAINT. REQ'D
WRA REPAIRABLE
PREV. MAINT MH/FH = λ ET # CREW
RECOMMEND BCM-9
WRA RFI
RECOMMEND BCM 2-8
MAT CONT. ADVISED MAINT CONTROL CLOSES OUT REGISTER
1
2
3
4

Figure 3

PREV ORG MH/FH = ((TURNAROUND λ * TURNAROUND ET * TURNAROUND CREW) + (SPECIAL λ * SPECIAL ET * SPECIAL CREW) + (PHASE λ * PHASE ET * PHASE CREW))/(1000*60)

CORR ORG MH/FH = ((REPAIR λ * REPAIR ET * REPAIR CREW) + (REPLACE λ * REPLACE ET * REPLACE CREW))/(1000*60)

ORG MH/FH = PREV ORG MH/FH + CORR ORG MH/FH

5.3 INTERMEDIATE MAINTENANCE MANHOURS PER FLIGHT HOUR (INT MH/FH)

INT MH/FH is also a summation of preventive and corrective time, and is computed as follows:

INT MH/FH = ((PREV λ * PREV ET * PREV CREW) + (REPAIR WRA λ * REPAIR WRA ET * REPAIR WRA CREW))/(1000*60)

6. SUMMARY OF RELIABILITY ANALYSIS

The system was analyzed for flight safety, mission, and maintenance malfunction Reliabilities. This analysis included predictions, allocations, Failure Mode and Effects Analysis, and test program design. All numerical reliability requirements were met, and no verifiable single failure points were found.

6.1 GENERAL DISCUSSION

Three types of Reliability have been analyzed:

a. Flight Safety Reliability
b. Mission Reliability
c. Maintenance Malfunction Reliability

Flight Safety Reliability is the probability that no hardware failure will cause a catastrophic accident. For this system, this is essentially equivalent to deployment of the raft(s) while flying.

For this system, Mission Reliability is defined as the probability that the rafts would successfully deploy whenever the system was actived.

Maintenance Malfunction Reliability is the probability of no hardware malfunction requiring maintenance action.

The simultaneous analysis of all three types of reliability is essential to truly optimize the system. For example, additional levels of redundancy tend to improve the first two types of reliability but maintenance malfunction reliability is degraded.

6.2 The following ground rules were used for design evaluation:

a. No single failure shall cause a flight safety loss.

b. No single failure shall cause a mission loss.

c. The probability of flight safety loss shall be in the "remote" category (Rfs greater than .9999999 or about 10 million hours between safety-affecting hardware failures).

d. Mission Reliability shall equal or exceed .90 for 439.65 flight hours (18 calendar months) under field conditions.

e. Mission Reliability shall equal or exceed .98 for one hour bench tests.

f. The system shall have a 90% probability of passing tests designed to demonstrate the requirements of ground rules 4 and 5 at the 90% confidence level.

g. Subject to the above constraints, Maintenance Malfunction Reliability shall be maximized.

h. The rafts themselves are considered Government Furnished Equipment (GFE) and are not subject to the above ground rules.

6.3 DESIGN CHANGE RATIONALE

Preliminary Reliability analysis indicated that the system as defined in D210-11002-1 was not capable of meeting the above ground rules. Accordingly, the design was modified to that shown in the schematic of Figure 4. The following are the rationale for these changes: (1) The preliminary Failure Mode and Effects Analysis identified several wiring single failure points for both flight safety and mission reliability (e.g. opens, shorts to power, and shorts to ground); (2) The pilot's manual fire capability was inhibited by the zero speed sensor, but the cabin switch was not. The preliminary reliability prediction indicated that single squibs even "Hi-Red" squibs could not meet the "bench" Mission Reliability requirement. Although the water sensing switches were capable of meeting all requirements, a significant improvement in both redundancy level and all numerical reliabilities could be realized by utilizing switching logic already on board the helicopter.

REVISED SCHEMATIC - AUTOMATED LIFE RAFT

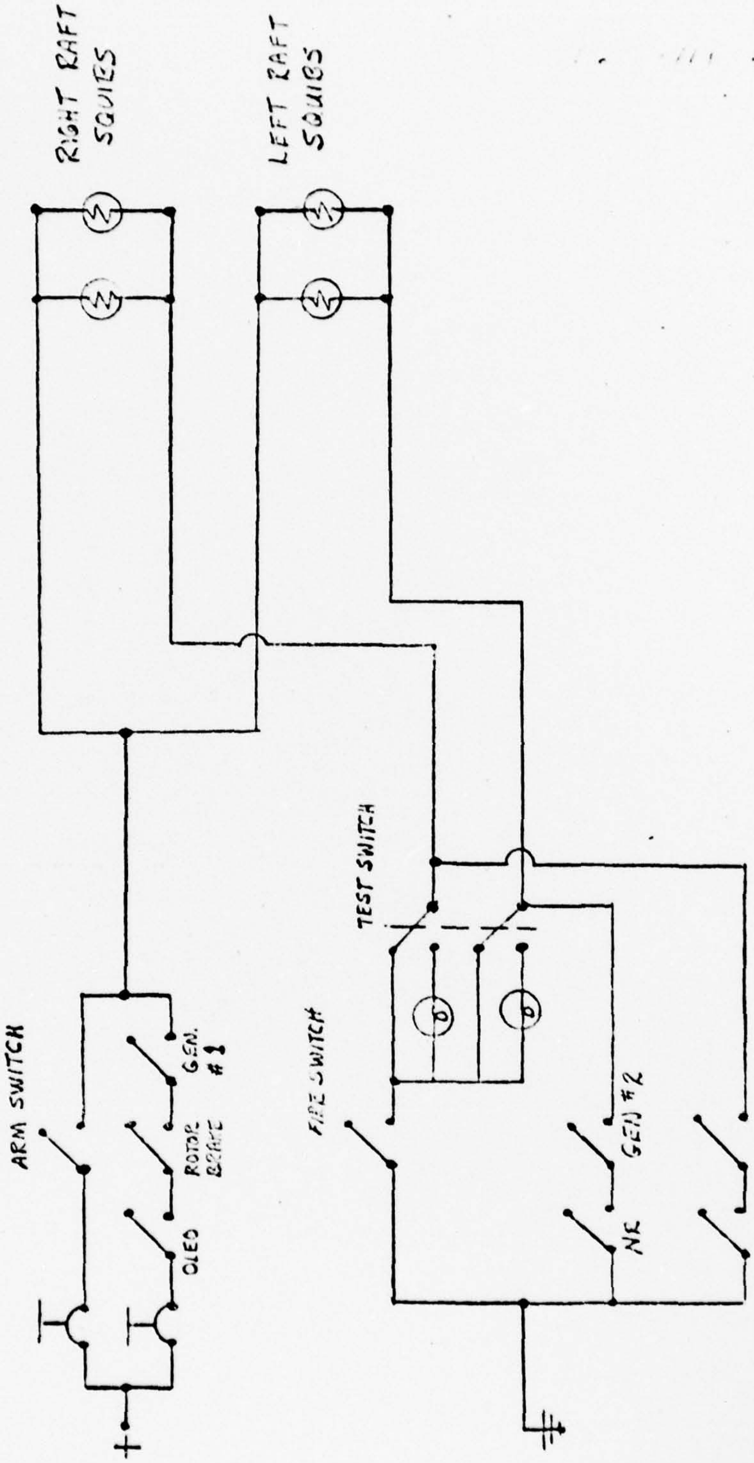


FIGURE 4

7. RELIABILITY BLOCK DIAGRAMS

Figures 5, 6, 7, and 8 are the reliability block diagrams for Maintenance Malfunction, "bench" Mission, "field" Mission, and Flight Safety Reliabilities respectively. Unless otherwise noted, all numbers are "effective" or "average" failure rates in failures per million hours. Numbers such as .0(8)123 are a short form for .00000000123 (likewise .9(5)123 = .99999123). MIL-STD-756 conventions are applicable.

8. RELIABILITY PREDICTIONS

Figure 9 is a computerized reliability prediction for the four different types of reliability. These predictions utilize the logical relationships (redundancies) shown in the Reliability Block Diagrams. All numbers are failure rates in failure per million hours. Converted to reliabilities, the system values are as follows:

	Failure Rate	Time (Hrs)	Predicted Reliabilit	equired iability
Maintenance Malfunction	632.380	1	.9(3)367	
"bench" Mission	24.009	1	.9(4)759	.98
"field" Mission	.061	439.65	.9(7)390	.90
Flight Safety	.0(8)175	439.65	.9(12)226	.9(7)

The Maintenance Malfunction value indicates an average time of 1581 flight hours between maintenance-requiring malfunctions. The remaining reliabilities exceed their requirements by a margin big enough to assure 90% probability of passing a 90% confidence test. These margins are also large enough to assure that a worst case (-3 sigma) deviation would still meet the requirements.

9. RELIABILITY ALLOCATIONS

Figure 10 is a computerized reliability allocation for the four different types of reliability. These allocations utilize the logical relationships (redundancies) shown in the Reliability Block Diagrams. All numbers are failure rates in failures per million hours. If the system level predicted failure rate is less than the requirements, the program allocates the predicted values to the components. If the system level predicted failure rate is greater than the requirement, the program allocates the required value to the components in proportion to their relative contribution to the system level prediction (proportioned burden apportionment).

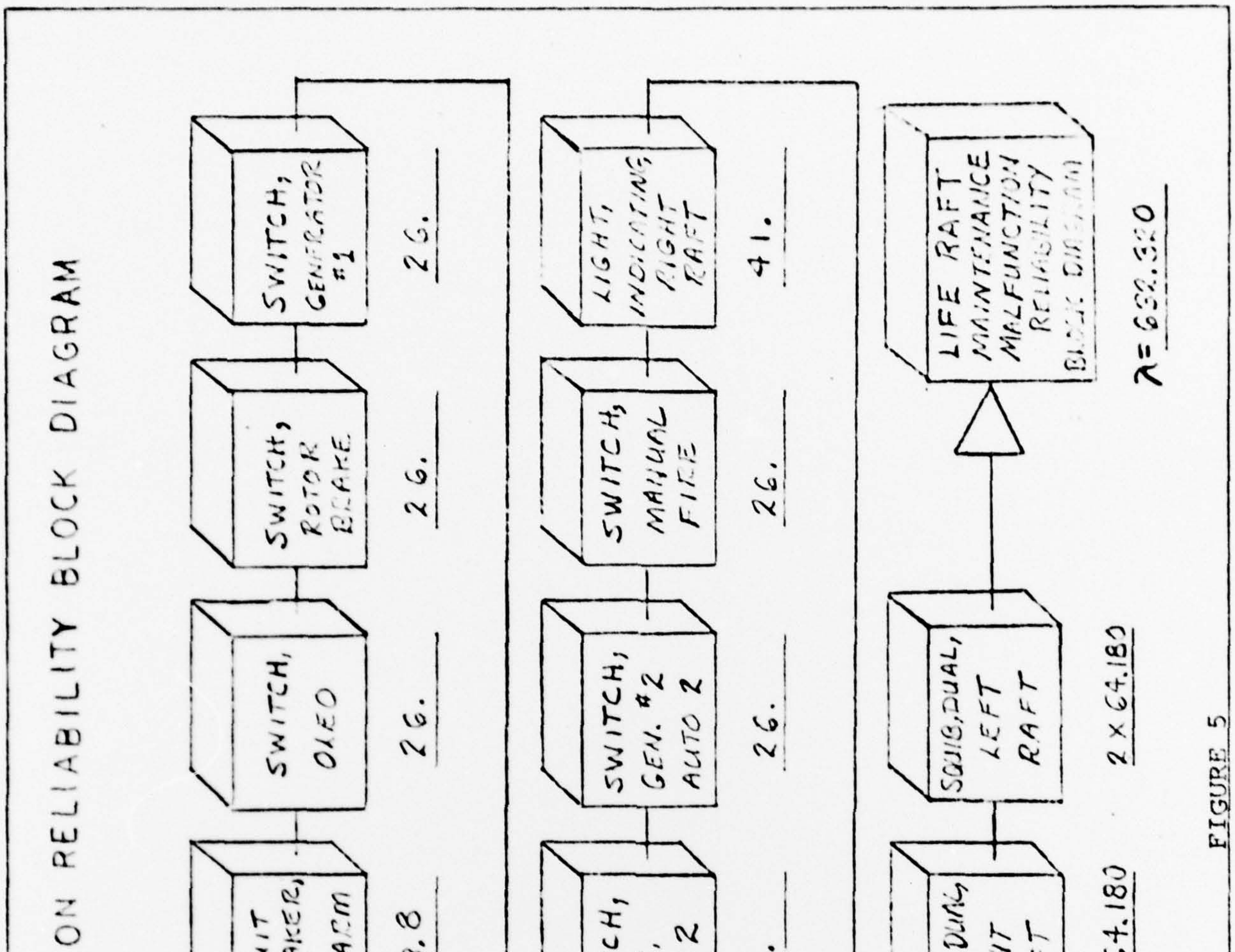
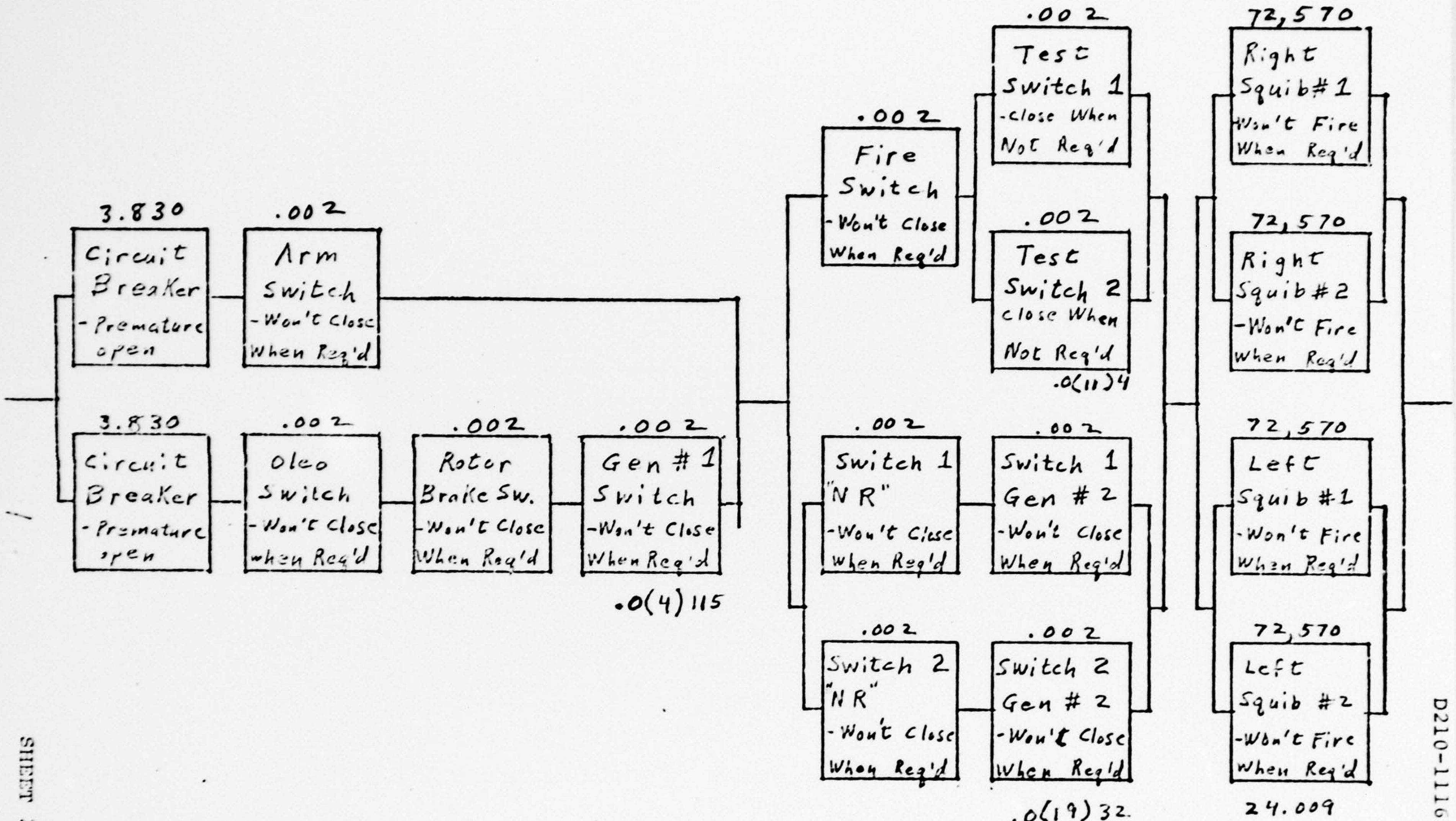


FIGURE 5

FORM 40284 (2/66)

LIFE RAFT RELIABILITY BLOCK DIAGRAM - MISSION-BENCH



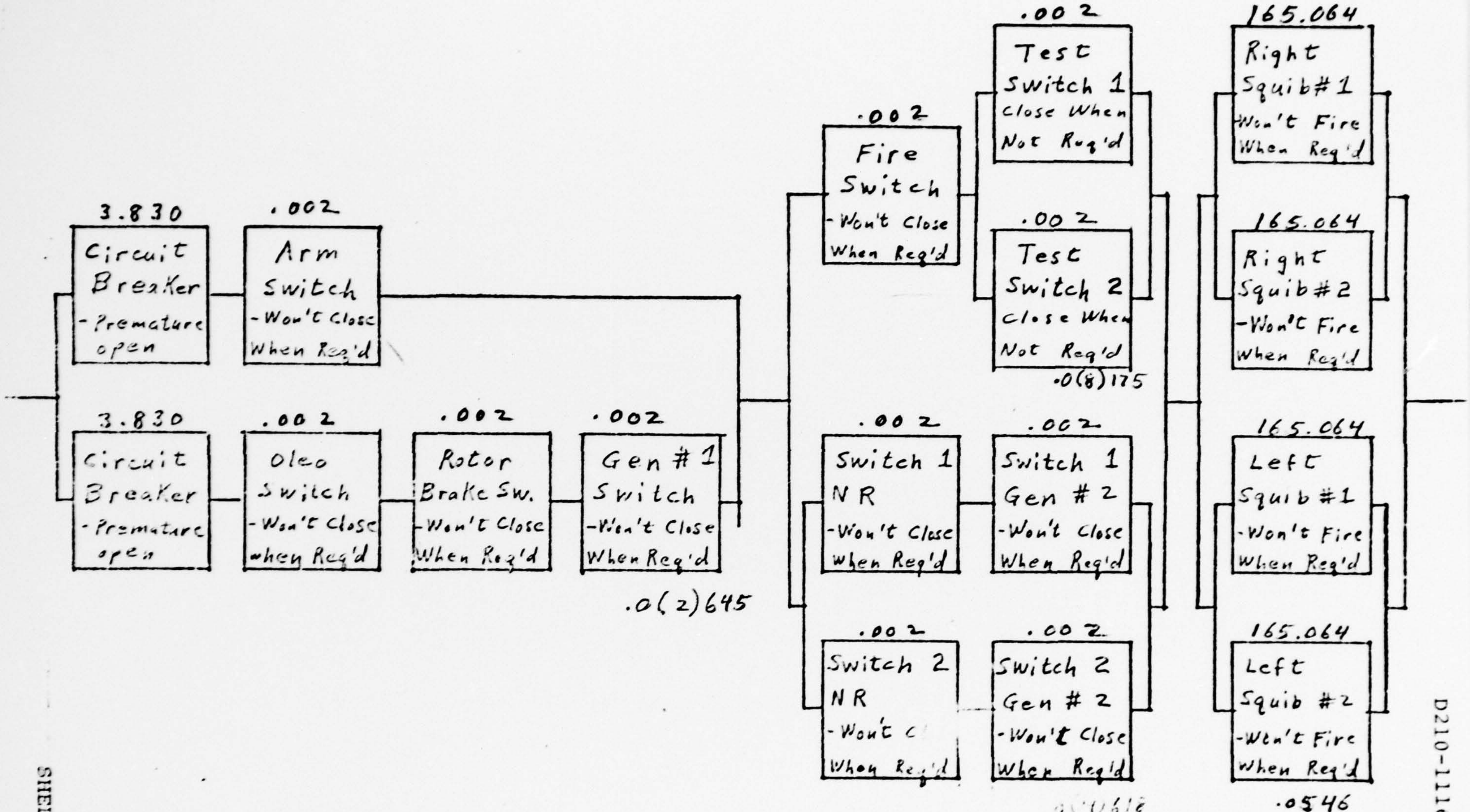
$\lambda = 24.0090115$

$R = .9999759$

$T = 1$ hour

Figure 6

'FE RAFT RELIABILITY BLOCK IAGRAM - MISSION-FIELD

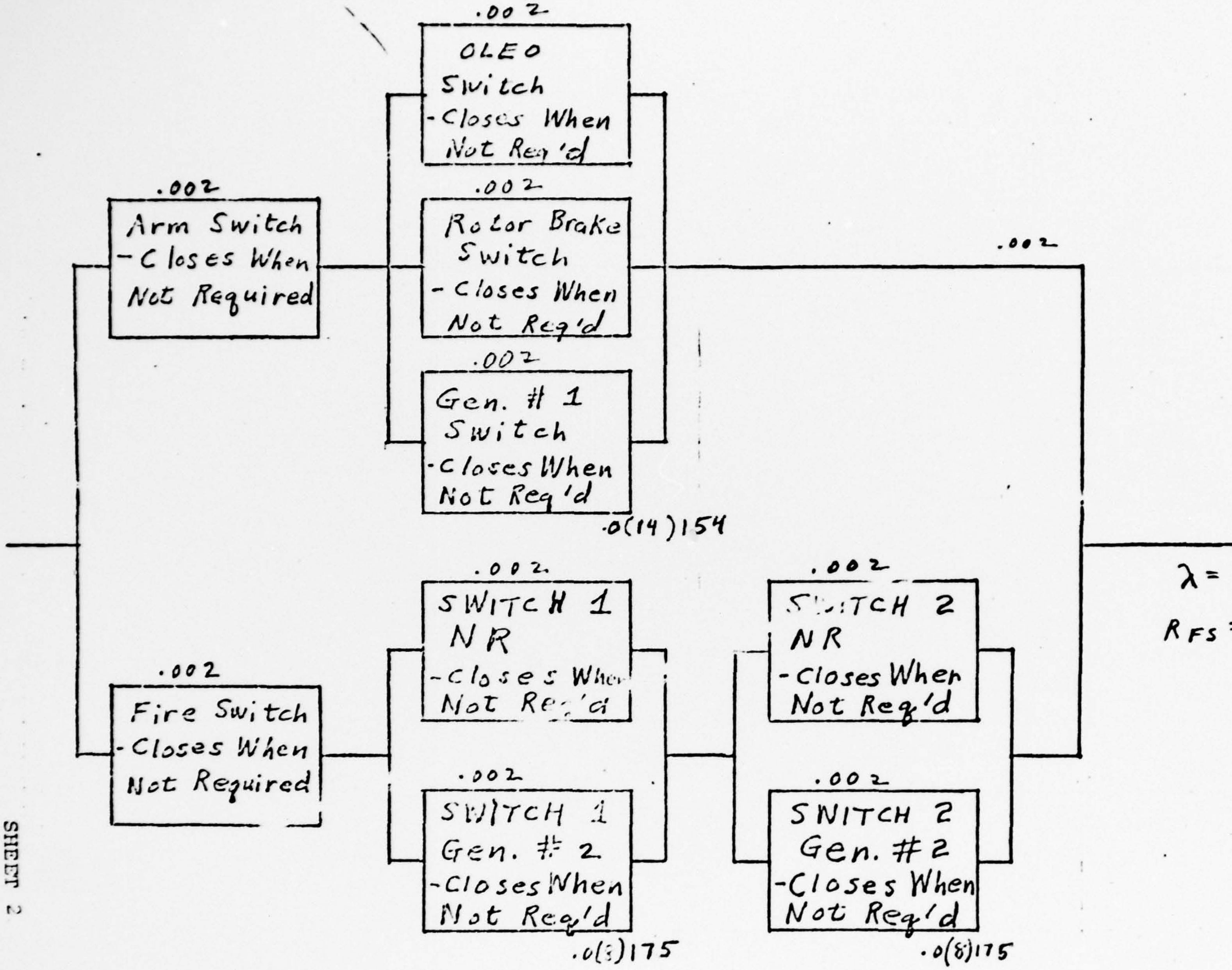


λ = .061063
R = .9999731

T = 439.65 (18 mo)

Figure 7

L FE RAFT RELIABILITY BLO K DIAGRAM – FLIGHT SA ETY



$\lambda = .0(8)17586$

$R_{FS} = .9(12)226$

$T = 439.65$ hrs (18 mo.)

Figure 8

		QTY	MM FR	M1 FR	M2 FR	FS FR	NAME	
1	999	1		R.061063	R24.00900	R.0000000	LIFE RAFT SYSTEM	
2	998	1		R.00645	R.0000115	R.002	'ARM' CIRCUIT	
3	997	1					MANUAL ARM CIRCUIT	
4	69	1	3.830	3.830	3.830	,0.	BREAKER,CIRCUIT	ARM
	75	1	26.	.002	.002	.002	SWITCH	ARM
		1X	29.830	3.832	3.832	0.002	TOTAL: MANUAL ARM CIRCUIT	
6	997	1				R0.	AUTOMATIC ARM CIRCUIT	
7	69	1	3.830	3.830	3.830	3.830	BREAKER,CIRCUIT	AUTO
8	75	1	26.	.002	.002	.002	SWITCH	OLEO
9	75	1	26.	.002	.002	.002	SWITCH	RTR BRAK
10	75	1	26.	.002	.002	.002	SWITCH	GEN #1
		1X	81.830	3.836	3.836	0.0	TOTAL: AUTOMATIC ARM CIRCUIT	
		1X	111.660	0.006	0.000	0.002	TOTAL: 'ARM' CIRCUIT	
11	998	1				R.0002	'FIRE' CIRCUIT	
12	997	1		R0.	R0.	R0.	AUTOMATIC FIRE CIRCUIT	
13	75	1	26.	.002	.002	.002	SWITCH	NR,1
14	75	1	26.	.002	.002	.002	SWITCH	GEN#2,1
15	75	1	26.	.002	.002	.002	SWITCH	NR,2
16	75	1	26.	.002	.002	.002	SWITCH	GEN#2,2
		1X	104.000	0.0	0.0	0.0	TOTAL: AUTOMATIC FIRE CIRCUIT	
1[illegible]	997	1		R.002	R.002	R.002	MANUAL FIRE CIRCUIT	
1[illegible]	75	1	26.	.002	.002	.002	SWITCH	FIRE
	79	2	41.	,0.	,0.	0.0	LIGHT,INDICATE	
20	75	2	26.	.002	.002	,0.	SWITCH	TEST
		1X	160.000	0.002	0.002	0.002	TOTAL: MANUAL FIRE CIRCUIT	
		1X	264.000	0.002	0.002	0.000	TOTAL: 'FIRE' CIRCUIT	
21	998	1		R.0546	R24.009		'DEPLOY RAFT' CIRCUIT	
22	997	2		R.0273	R12.0045		RAFT CIRCUITS	
23	145	2	64.180	,165.064	,72570.	,0.	SQUIB	
		2X	128.360	0.027	12.005	0.0	TOTAL: RAFT CIRCUITS	
		1X	256.720	0.055	24.009	0.0	TOTAL: 'DEPLOY RAFT' CIRCUIT	
		1X	632.380	0.061	24.009	0.0	TOTAL: LIFE RAFT SYSTEM	

PREDICTION REPORT

FIGURE 9

FAILURE RATE ALLOCATION

NOTE: ALL FAILURE RATES = FAILURES PER MILLION HOURS

MM FR : MAINTENANCE MALFUNCTION RELIABILITY FAILURE RATE
M1 FR : FIELD MISSION RELIABILITY FAILURE RATE
M2 FR : BENCH MISSION RELIABILITY FAILURE RATE
FS FR : FLIGHT SAFETY FAILURE RATE

PREDICTIONS:

MM	=	632.820
M1	=	0.061
M2	=	24.009
FS	=	0.000000

REQUIREMENTS:

MM	=	632.820
M1	=	239.646
M2	=	20202.707
FS	=	0.000227

FIGURE 10

		QTY	MM FR	FIELD FR	BENCH FR	FS FR	NAME	
1	999	1		R.061063	R24.00900	R.0000000	LIFE RAFT SYSTEM	
		1X	0.0	0.061	24.009	0.0	SUBTOTAL	
2	998	1		R.00645	R.0000115	R.002	'ARM' CIRCUIT	
		1X	0.0	0.006	0.000	0.002	SUBTOTAL	
3	997	1					MANUAL ARM CIRCUIT	
4	69	1	3.830	3.830	3.830	,0.	BREAKER	ARM
5	75	1	26.	.002	.002	.002	SWITCH	ARM
		1X	29.806	3.832	3.832	0.002	TOTAL: MANUAL ARM CIRCUIT	
6	997	1				R0.	AUTOMATIC ARM CIRCUIT	
7	69	1	3.830	3.830	3.830	3.830	BREAKER	AUTO
8	75	1	26.	.002	.002	.002	SWITCH	CLED
9	75	1	26.	.002	.002	.002	SWITCH	RTR BRAK
10	75	1	26.	.002	.002	.002	SWITCH	GEN #1
		1X	81.765	3.836	3.836	0.0	TOTAL: AUTOMATIC ARM CIRCUIT	
		1X	111.572	0.006	0.000	0.002	TOTAL: 'ARM' CIRCUIT	
11	998	1				R.0002	'FIRE' CIRCUIT	
		1X	0.0	0.0	0.0	0.000	SUBTOTAL	
12	997	1		R0.	R0.	R0.	AUTOMATIC FIRE CIRCUIT	
13	75	1	26.	.002	.002	.002	SWITCH	NR,1
14	75	1	26.	.002	.002	.002	SWITCH	GEN#2,1
15	75	1	26.	.002	.002	.002	SWITCH	NR,2
16	75	1	26.	.002	.002	.002	SWITCH	GEN#2,2
		1X	103.918	0.0	0.0	0.0	TOTAL: AUTOMATIC FIRE CIRCUIT	
17	997	1		R.002	R.002	R.002	MANUAL FIRE CIRCUIT	
18	75	1	26.	.002	.002	.002	SWITCH	FIRE
19	79	2	41.	,0.	,0.	0.0	LIGHT,INDICATE	
20	75	2	26.	.002	.002	,0.	SWITCH	TEST
		1X	159.874	0.002	0.002	0.002	TOTAL: MANUAL FIRE CIRCUIT	
		1X	263.791	0.002	0.002	0.000	TOTAL: 'FIRE' CIRCUIT	
21	998	1		R.0546	R24.009		'DEPLOY RAFT' CIRCUIT	
		1X	0.0	0.055	24.009	0.0	SUBTOTAL	
22	997	2		R.0273	R12.0045		RAFT CIRCUITS	
23	145	2	64.180	,155.064	,72570.	,0.	SQUIB	
		2X	128.259	0.027	12.005	0.0	TOTAL: RAFT CIRCUITS	
		1X	256.517	0.055	24.009	0.0	TOTAL: 'DEPLOY RAFT' CIRCUIT	
		1X	631.880	0.061	24.009	0.0	TOTAL: LIFE RAFT SYSTEM	

ALLOCATION

FIGURE 10 CONTINUED

10. FAILURE MODE AND EFFECTS ANALYSIS (FMEA)

Figure 11 is a computerized Failure Mode and Effects Analysis (FMEA). "Opens", "shorts", "shorts to power", and "shorts to ground" were analyzed. Since both inputs and outputs were analyzed, wiring failures are also covered. After redesign, no mission single failure points were identified. Auto-ignition of the squibs would be a flight safety single failure point, but we were unable to identify any recorded instance of this mode. The basic technique for protection against shorts to power and shorts to ground is switch disconnection of both power and ground connections. The technique-in conjunction with twisted pair power/ground wiring-gives better protection against EMI induced firing that is possible with shielded wiring.

11. RELIABILITY TEST PROGRAM

The requirements for this program do not specifically call for a Reliability Demonstration Test. However, they do say that:

a. Each system shall be designed for a probability of success (reliability) of .98 at the 90% confidence level for bench testing.

b. Each helicopter system shall be capable of demonstrating a reliability of .90 at the 90% confidence level when completely installed in the subject helicopter.

These require that a test program be designed so that the system would be capable of passing such a test if it were run. MIL-STD-781 gives test plans which demonstrate at 90% (and other) levels of confidence, but this, by itself, is insufficient to respond to the above requirements! The reason is that high confidence tests (such as MIL-STD-781) are so powerful in rejecting bad equipment (less than the requirement) that it also has a high probability of rejecting good equipment! For example, take requirement a. above (R of .98 at 90% confidence). Figure 12 shows that if you were to conduct a test of 114 components (or systems) with no failures, you would demonstrate a reliability of .98 at the 90% confidence level. Now suppose you entered this test with 114 components with a true reliability of exactly .98? You would find that you have only a 10% chance of passing the test.* In other words, if you repeated this test a number of times, an average of 9 out of 10 tests would "flunk" (have one or more failures). It turns out that just to have a 50-50 chance of passing the test, you must go into the test with a true reliability of .99394, even though the requirement was only .98. In fact, in order to have a

*The theoretical error in this statement is recognized but is not significant to the conclusions developed.

FAILURE MODE AND EFFECTS ANALYSIS

NAME		FAILURE MODE	EFFECT
LIFE RAFT SYSTEM			
'ARM' CIRCUIT			
BREAKER,CIRCUIT (ARM)		-NO OP.WHEN REQD	WON'T MANUAL ARM
		-OP.WHEN NOT REQD	WON'T DISCONNECT A SHORT
SWITCH	ARM	-SHORT,IN TO OUT	MANUAL ERRONEOUSLY ARMED
		-OPEN	WON'T MANUAL ARM
		-GROUNDED	WON'T ARM(BOTH BREAKERS POP)
		-SHORT TO B+	ERRONEOUSLY ARMED
		-INPUT OPEN	WON'T MANUAL ARM
		-INPUT GROUNDED	WON'T MANUAL ARM(BREAKER POPS)
		-INPUT B+ SHORT	BREAKER BYPASSED
BREAKER,CIRCUIT (AUTO)		-NO OP.WHEN REQD	WON'T AUTO ARM
		-OP.WHEN NOT REQD	WON'T DISCONNECT A SHORT
SWITCH	OLEC	-SHORT,IN TO OUT	WILL ARM ON LANDING
		-OPEN	WON'T AUTO ARM
		-GROUNDED	BREAKER POPS ON LANDING
		-SHORT TO B+	WILL ARM ON LANDING
		-INPUT OPEN	WON'T AUTO ARM
		-INPUT GROUNDED	WON'T AUTO ARM(BREAKER POPS)
		-INPUT B+ SHORT	BREAKER BYPASSED
SWITCH	R BRAKE	-SHORT,IN TO OUT	WILL FIRE ON WATER SHUTDOWN
		-OPEN	WON'T AUTO ARM
		-GROUNDED	BREAKER POPS ON LANDING
		-SHORT TO B+	ARMS ON SHUTDOWN
		-INPUT OPEN	WON'T AUTO ARM
		-INPUT GROUNDED	BREAKER POPS ON WATER LANDING
		-INPUT B+ SHORT	WILL FIRE ON LANDING
SWITCH	GEN #1	-SHORT,IN TO OUT	PARTIAL AUTO ARM
		-OPEN	WON'T AUTO ARM
		-GROUNDED	POPS BREAKER ON WATER LANDING OR TEST
		-SHORT TO B+	ERRONEOUSLY ARMED
		-INPUT OPEN	WON'T AUTO ARM
		-INPUT GROUNDED	WILL POP BREAKER ON WATER LANDING
		-INPUT B+ SHORT	ARMS ON SHUTDOWN
'FIRE' CIRCUIT			
SWITCH	NR	-SHORT,IN TO OUT	PARTIAL LEFT SQUIB AUTO FIRE
		-OPEN	LEFT SQUIBS WON'T AUTO FIRE
		-GROUNDED	LEFT SQUIB WILL AUTO FIRE ON SHUTDOWN
		-SHORT TO B+	ELECTRICAL SHORT ON SHUTDOWN
		-INPUT OPEN	LEFT SQUIBS WON'T AUTO FIRE
		-INPUT GROUNDED	NO EFFECT
		-INPUT B+ SHORT	ELECTRICAL SHORT
SWITCH	GEN#2	-SHORT,IN TO OUT	PARTIAL LEFT SQUIB AUTO FIRE
		-OPEN	LEFT SQUIBS WON'T AUTO FIRE
		-GROUNDED	LEFT SQUIBS WILL FIRE IF ARMED
		-SHORT TO B+	LEFT SQUIBS WON'T FIRE(TEST WON'T CATCH)
		-INPUT OPEN	LEFT SQUIBS WON'T AUTO FIRE
		-INPUT GROUNDED	PARTIAL LEFT SQUIB AUTO FIRE
		-INPUT B+ SHORT	ELECTRICAL SHORT ON SHUTDOWN
SWITCH	NR	-SHORT,IN TO OUT	PARTIAL RIGHT SQUIB AUTO FIRE
		-OPEN	RIGHT SQUIBS WON'T AUTO FIRE
		-GROUNDED	RIGHT SQUIB WILL AUTO FIRE ON SHUTDOWN
		-SHORT TO B+	ELECTRICAL SHORT ON SHUTDOWN
		-INPUT OPEN	RIGHT SQUIBS WON'T AUTO FIRE
		-INPUT GROUNDED	NO EFFECT
		-INPUT B+ SHORT	ELECTRICAL SHORT

FIGURE 11

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SWITCH	GEN#2	-SHORT,IN TO OUT	PARTIAL RIGHT SQUIB AUTO FIRE
		-OPEN	RIGHT SQUIBS WON'T AUTO FIRE
		-GROUNDED	RIGHT SQUIBS WILL FIRE IF ARMED
		-SHORT TO B+	RIGHT SQUIBS WON'T FIRE(TEST WON'T CATCH
		-INPUT OPEN	RIGHT SQUIBS WON'T AUTO FIRE
		-INPUT GROUNDED	PARTIAL RIGHT SQUIB AUTO FIRE
		-INPUT B+ SHORT	ELECTRICAL SHORT ON SHUTDOWN
SWITCH	FIRE	-SHORT,IN TO OUT	WILL FIRE IF ARMED
		-OPEN	WON'T MANUAL FIRE
		-GROUNDED	WON'T MANUAL FIRE
		-SHORT TO B+	ELECTRICAL SHORT ON SHUTDOWN
		-INPUT OPEN	WON'T MANUAL FIRE
		-INPUT GROUNDED	NO EFFECT
		-INPUT B+ SHORT	ELECTRICAL SHORT
LIGHT,INDICATE	RIGHT	-SHORT,IN TO OUT	WILL FIRE RIGHT SQUIBS IN TEST
		-OPEN	WON'T INDICATE ON TEST
LIGHT,INDICATE	LEFT	-SHORT,IN TO OUT	WILL FIRE LEFT SQUIBS IN TEST
		-OPEN	WON'T INDICATE ON TEST
SWITCH	TEST	-SHORT,IN TO OUT	WON'T TEST RIGHT SQUIBS
		-OPEN	RIGHT SQUIB WON'T FIRE MANUALLY
		-GROUNDED	RIGHT SQUIB WILL FIRE IF ARMED
		-SHORT TO B+	RIGHT SQUIBS WON'T FIRE MANUALLY
		-INPUT OPEN	RIGHT SQUIBS WON'T FIRE MANUALLY
		-INPUT GROUNDED	WILL FIRE IF ARMED
		-INPUT B+ SHORT	ELECTRICAL SHORT ON SHUTDOWN
SWITCH	TEST	-SHORT,IN TO OUT	WON'T TEST LEFT SQUIBS
		-OPEN	LEFT SQUIB WON'T FIRE MANUALLY
		-GROUNDED	LEFT SQUIB WILL FIRE IF ARMED
		-SHORT TO B+	LEFT SQUIBS WON'T FIRE MANUALLY
		-INPUT OPEN	LEFT SQUIBS WON'T FIRE MANUALLY
		-INPUT GROUNDED	WILL FIRE IF ARMED
		-INPUT B+ SHORT	ELECTRICAL SHORT ON SHUTDOWN
'DEPLOY RAFT' CIRCUIT			
SQUIB	RIGHT	-NO OP.WHEN REQD	SINGLE FAILURE POINT(NO RECORDED INSTANCE
		-OP.WHEN NOT RQD	NO EFFECT(OTHER SQUIB WILL FIRE)
SQUIB	RIGHT	-NO OP.WHEN REQD	SINGLE FAILURE POINT(NO RECORDED INSTANCE
		-OP.WHEN NOT RQD	NO EFFECT(OTHER SQUIB WILL FIRE)
SQUIB	LEFT	-NO OP.WHEN REQD	SINGLE FAILURE POINT(NO RECORDED INSTANCE
		-OP.WHEN NOT RQD	NO EFFECT(OTHER SQUIB WILL FIRE)
SQUIB	LEFT	-NO OP.WHEN REQD	SINGLE FAILURE POINT(NO RECORDED INSTANCE
		-OP.WHEN NOT RQD	NO EFFECT(OTHER SQUIB WILL FIRE)

FIGURE 11 (CONTINUED)

good (e.g., 90%) probability of passing the test, you must go into the test with a true reliability of .999075! In order to better understand what this means, consider the "mean time between failure" or MTBF. A reliability of 198 for a one hour mission is equivalent to an MTBF of 50 hours. A reliability of .99394 is equivalent to an MTBR of 164 hours! A reliability of .999076 is equivalent to an MTBF of 1,081 hours! Thus, the true MTBF must be 22 times greater than the required - just to have a reasonably good probability of passing the test! The probability of not passing the test is usually referred to as "producer's risk" (although it should be realized that in the long run, the consumer actually pays for it). Thus, producer's risk is the probability of rejecting good equipment. One minus the confidence (as a decimal) is equivalent to "consumer's risk" (risk of accepting bad equipment). The convention is to set up a "fair" testing program (consumer's risk equals producer's risk or probability of passing equals confidence), and Figure 12 shows the results for requirement a. Note that by increasing the number of allowable failures (and the number of tests!) the "true" or designed reliability can be lowered. Obviously there is a practical limit to this approach. Even if we were to increase the number of allowable failures to 52, the design reliability would still have to be .9859 or an MTBF of 70 hours which is still 142% of the required MTBF of 50 hours. Furthermore, the destructive testing of 3,121 systems is probably impractical from both the time and cost standpoint. Thus a balance must be struck between the designed (true) reliability and the number of tests. If we use the reliability prediction as an estimate of the true reliability, the bench mission prediction of R = .9999759 allows selection of the "zero failure in 114 tests" test program. If we allow for an "order of magnitude" error in the prediction: R = .999759, the test program can still be zero failures in 114 tests" because this is the smallest program with a 90% probability of passing. It should be noted that this is the primary reason why the design was not frozen when the prediction first reached R = .98. Figure 13 is an equivalent table for the "field" mission and the predicted value of R = .999999939 allows the selection of the "zero failure in 22 tests" test program. The time value of 439.65 flight hours was based on 18 months on each of 275 aircraft - the test being an actual firing of the system just prior to refurbishment. This approach would assure testing under true field conditions and avoid the cost of special purchases and flights strictly for test purposes.

11.1 DEVELOPMENT (PROBLEM IDENTIFICATION) TESTING

The primary reliability testing program will be problem identification testing. The purpose of this type of testing is confirmation of failure effects as identified by the FMEA. Specifically, each FMEA failure mode is artificially induced into the system and the resulting system effect is noted. In addition, system level interface failures are induced to confirm the logic of the Reliability Block Diagrams. Due to the artificial creation of failure modes, no attempt will be made to calculate failure rates based on this data.

BENCH TEST TRADEOFF FACTORS (T = 1 hour)

R = .99 at 90% CONFIDENCE

F	N	CONF	R_T for 90% PA	θ_T for 90% PA	θ_T/θ_{REQ}
0	114	.900052340	.9990762119.13	1081	21.859
1	194	.901537749	.9972553822161	363	7.35
2	265	.900767174	.9958541254.3	239	4.83
3	333	.901013472	.9947565229.8	187	3.83
4	398	.900376362	.9938758677.26	162	3.28
5	462	.900445362	.9931639956.76	145	2.94
6	525	.900683558	.9925664460.51	134	2.70
7	587	.900420515	.9920520832.13	125	2.51
8	648	.900712301	.9915998629.26	118	2.39
9	708	.900278402	.9911955119.27	113	2.28
10	768	.900326163	.9908405771.415	108	2.19
11	828	.900743787	.9905260711.41	105	2.122
12	887	.900655707	.9902347735.42	101	2.058
13	945	.900072198	.9899104192.16	99	2.002
14	1004	.900508008	.9897224105.22	96	1.95
15	1062	.900315722	.9894955148.61	95	1.91
16	1120	.900471098	.9891887717.495	93	1.87
17	1177	.900008779	.9890879.59.136	91	1.84
18	1235	.900593622	.9887154751.47	90	1.81
19	1292	.900226420	.9887378.63552	89	1.78
20	1349	.900194588	.9885773314.37	87	1.75
21	1406	.900252022	.9884270.3314	86	1.73
22	1463	.90041[illegible]	.9882863.4.717	85	1.71
23	1519	.900247861	.9881471222.27	84	1.69
24	1576	.900381900	.9880232772.75	83	1.68
25	1632	.900186643	.9878779.31551	82	1.65
26	1688	.900067815	.9877815835.47	81	1.64
27	1744	.900019697	.9876703.35.258	81	1.63
28	1800	.900024939	.9875648.0.074	80	1.61
29	1856	.900137[illegible]	.9874.6.579150	79	1.60
30	1912	.900232379	.98736115.4216	77	1.59
31	1968	.900404286	.9872782159.11	78	1.58
32	2023	.900[illegible]			
33	2079	.900344039			
34	2134	.900117955			
35	2190	.900454.58	.9869412220.70	76	1.54
36	2245	.900310.61			
37	2300	.900205178	.9867803.21413	75	1.52
38	2355	.900137830			
39	2410	.900103852			
40	2465	.900015.72			
41	2520	.900.2.798			
42	2575	.900183829			
43	2630	.90026454.			
44	2685	.900.41319			
45	2739	.900.32677			
46	2794	.900.75711			
47	2849	.900.5.712			
48	29[illegible]	.900[illegible]			
49	2958	.900[illegible]77			
50	3012	[illegible]	.98[illegible]	71	[illegible]
51	[illegible]	[illegible]			
52	3121	[illegible]	.98[illegible]	[illegible]	

FIGURE 12

FIELD TEST TRADE-OFF REQUIREMENTS

R = .90 at 90% CONFIDENCE

F	N	CONF	$R_?$ for = RISK
0	22	.901522909	.99522233518
1	38	.904704869	.98591697
2	52	.903366714	.978619
3	65	.900447174	.97289
4	78	.900605676	.9684915
5	91	.902427110	.9655[illegible]87417
6	104	.903764016	.9[illegible]216118
7	116	.903612658	.95944535
8	128	.902872620	.95721541
9	140	.902736185	.95510[illegible]3191
10	150	.903054946	.955345683172
11	164	.903717453	.951785804857
12	175	.900568851	.950107901560
13	187	.901358866	.94[illegible]
14	199	.903294126	.94774[illegible]82
15	210	.901107564	.945473106156
16	222	.902876088	.94555081[illegible]
17	233	.901140375	.944464711760
18	245	.903125862	.943291121365
19	256	.901737326	.94275078[illegible]
20	267	.902307777	.941874578[illegible]
21	279	.902743177	.94126[illegible]
22	290	.901757508	.940[illegible]6630841
23	301	.900877259	.939771171193
24	312	.900130424	.939048332496
25	324	.902552997	.938633791233
26	335	.901953607	.938022525576
27	346	.901430670	.937441781598
28	357	.900783876	.936890[illegible]3
29	368	.900605579	
30	379	.900291681	.935869528955
31	390	.900036657	.935394969159

FIGURE 13